HIGH-SPEED DATA SYSTEMS FOR PULSED POWER APPLICATIONS

Robert E. Hebner
National Bureau of Standards
Gaithersburg, MD 20899

Abstract

Data acquisition systems for pulse power applications generally must provide nanosecond resolution, operate in an environment of high levels of electromagnetic interference, and acquire significant amounts of data simultaneously. To meet these demands, electrical systems have been used and optical systems are being introduced. Voluntary standards have been and are being developed which categorize the errors in the electrical measurement systems. The development of optical systems is too immature for similar standardization.

Introduction

Data acquisition systems for pulse power applications are generally designed for specific applications and the degree of standardization is rather small. Because of the high cost of hardware, software, and the data itself, some laboratories and funding agencies have attempted to stimulate the adoption of common measurement approaches, but the rapid development of test and measurement technology has meant that system improvement has outpaced system standardization.

There are, however, common demands on pulsed power data acquisition systems which do lead to some commonality in the various approaches. First, these systems usually require nanosecond resolution (plus or minus an order of magnitude or two depending upon the application) of low duty cycle events. Because the events are not identical from shot-to-shot, sampling techniques cannot generally be used to improve temporal resolution and accuracy.

A second demand is placed on the data acquisition system because the pulsed power systems which produce the data also, generally, produce high levels of electromagnetic interference. This situation necessitates operation of the data handling system at high signal levels and particular attention must be paid to the grounding and shielding of systems. In some cases, optical coupling has been used between the pulsed power equipment and the data acquisition system to reduce the effects of conducted and radiated electromagnetic interference.

A third characteristic is that pulsed power systems frequently require significant amounts of data to be acquired simultaneously. The simultaneous acquisition necessitates a number of parallel data channels, each with its own, short term (buffer) storage.

Summary of the Types of Measurement Systems Used in Pulsed Power Applications

A convenient classification of the various types of high speed data acquisition systems used in pulsed power applications is presented in Table 1. The conventional system is a totally electrical one consisting of appropriate devices to sense and scale the signals of interest, e.g. E-dot probes, dividers, B-dot probes, or Rogowski coils. Coaxial cables are used to transport the electrical signal from the transducer to the data recording system which typically consists of oscilloscopes and/or electronic waveform recorders. The data can be photographed and saved, but most modern systems rely on the storage of digitized data by a computer system.

In the first type of optical system listed, the coaxial cable is replaced by a optical fiber and the information is transmitted optically rather than electrically. The optical connection provides natural immunity to electrical noise. However, the immunity is gained at the expense of increased complexity (and possibly decreased speed and accuracy) as the electrical signal must be converted to an optical signal for transmission and then the electrical signal must be reconstructed for recording and storage. In this type of system, the conversion and reconstruction are performed using active circuitry. A wide variety of such optical data links is commercially available.

Table 1: Existing Types of Measurement Systems

System Type	Transducer	Cable	Data Recording System	Data Storage System
Conventional	E-Dot, B-Dot, etc.	Coaxial	Oscilloscope, Waveform Recorder, etc.	Computer, Photographs, etc.
Optical: Type 1	E-Dot, B-Dot, etc.	Optical Fiber with Transmitter & Receiver	Oscilloscope, Waveform Recorder, etc.	Computer, Photographs, etc.
Optical: Type 2	Electro-Optical or Magneto-Optical	Optical Fiber	Oscilloscope, Waveform Recorder, etc.	Computer, Photographs, etc.
Optical: Type 3	Electro-Optical or Magneto-Optical	Optical Fiber	Optical Waveform Recorder	Computer

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14. ABSTRACT

Data acquisition systems for pulse power applications generally must provide nanosecond resolution, operate in an environment of high levels of electromagnetic interference, and acquire significant amounts of data simultaneously. To meet these demands, electrical systems have been used and optical systems are being introduced. Voluntary standards have been and are being developed which categorize the errors in the electrical measurement systems. The development of optical systems is too immature for similar standardization.

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The second type of optical system differs from the first type in that the second type uses a passive optical sensor to replace the conventional electrical sensor. For the high speeds required in pulsed power applications, these sensors are usually based on the Pockels, the Faraday, or the Kerr effect [1]. Sensors based on electromechanical or magnetomechanical effects are also being developed for lower frequency applications [2]. Over the entire frequency range, these transducers generally are designed so that the electrical signal to be measured modulates the intensity of the light beam which is passed through the system. A photodetector is used to provide an electrical signal to the waveform recorder.

The third type of optical system replaces the electrical waveform recorder with an optical detection system based on an image converter camera. In this case, the transducer, the cable, and the data recording system are all optical components.

It should be stressed that the division of the optical systems into three types was made only to provide a convenient means to compare and contrast the various components in the measurement systems. Hybrids of these system types can and do exist. One such example is the recording of signals at frequencies of a few gigahertz. Conventional transducers (antennas) and optical transmitters exist which can operate in this frequency range. Recording the information, however, is more problematical. One solution is to detect the optical signal from the optical transmitter using a high speed camera in the streak mode. Then the light intensity as a function of time at the camera can be related to the electrical signal as a function of time at the antenna.

Optical Systems

The motivation for the development and application of optical techniques in high speed data systems can be divided into three general categories:

1. Electrical isolation.

2. Reduced size, expense, and complexity of the transducer.

3. Improvement of measurement accuracy.

The improved electrical isolation is obtained because there is no need for electrical cables to connect the high power generator to the measurement system. Thus the system provides inherent protection against ground currents and electromagnetic interference.

The transducers in an optical system are made of some optically active material and can be separated into two categories which depend upon the mechanism by which the light beam is modified. The first mechanism is an optical effect wherein an electric or magnetic field interacts directly with the atoms, molecules, or electrons in the transducer to change its index of refraction. Systems which operate on the basis of the Faraday effect, the Pockels effect, or the Kerr effect are examples of this mechanism. The second mechanism is a mechanical effect by which the signal to be measured produces a mechanical deformation of the sensor, thus producing a change in the optical transmission through the sensor. These transducers are generally made of glass, crystalline material, or the electrical insulating materials which already exist in the system. They are typically much smaller and lighter than the dividers or the transformers that they are designed to replace.

Finally, optical measurement techniques can improve the accuracy of measurements in selected applications. If the optical system is configured so that the signal to be measured causes a large optical phase shift, for example, the transducer effectively converts the amplitude modulated signal to be measured to a frequency modulated signal. This permits the more accurate measurement of signal amplitude than is given by the oscilloscope or the waveform recorder which is used to record the signal [3].

Data Recording Systems

The three primary data recording systems, the oscilloscope, the electronic waveform recorder, and the photonic waveform recorder, are shown schematically in Figure 1. The oldest system and the one based on the most mature technology is, of course, the oscilloscope. Even though there are anecdotal stories of interlaboratory comparisons differing by several percent when the voltage was determined from the same oscilloscope photograph, experience has shown that measurements can be made of single pulses with uncertainties as low as a few tenths of a percent of the peak value of the pulse. Because the oscilloscope is a well established device, there is an international standard which catalogues the common sources of errors in oscilloscope-based impulse measurements [4].

It should be noted in Figure 1 that both the oscilloscope and the waveform recorder have analog input circuitry, so similar errors due to these circuits would be expected in each case. The oscilloscope also contains a cathode ray tube which, depending upon the technology used, may or may not be part of the digital conversion process used in the waveform recorder. It would, therefore, be anticipated that each technology could also possess unique errors. This situation is

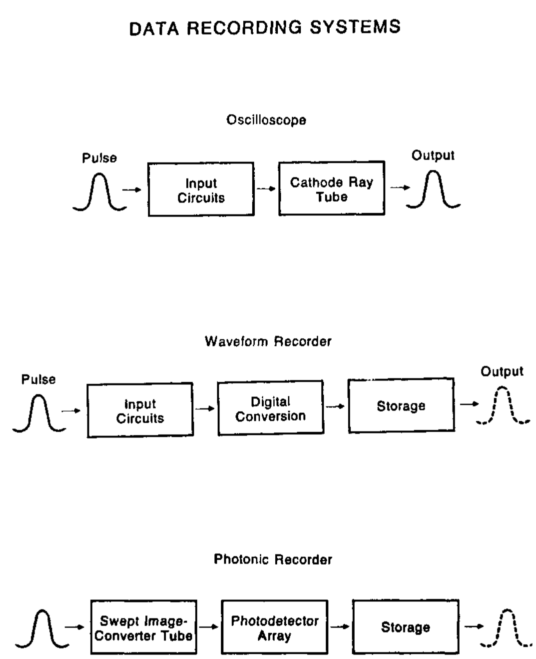

Figure 1 Schematic representation of the three primary data recording systems, the oscilloscope, the waveform recorder, and the photonic recorder.

illustrated in the examples shown in Table 2. The error sources in Table 2 are extracted from a published standard on transient measurements using oscilloscopes [4] and from a draft standard on waveform recorders which is presently being developed by a committee of the Institute of Electrical and Electronic Engineers [5].

Table 2: Specified Error Sources

Oscilloscopes	Electronic Recorders
Transfer Characteristics	Analog Bandwidth
Risetime	
Response Time	Step Response Parameters
Bandwidth	
Input Impedance	Input Impedance
Electromagnetic Interference	Noise
Non-Linearity	Linearity
Geometric Distortions	
Trapezoidal	
Pin Cushion/Barrel	
Non-Orthogonality	
	Effective Bits
	Acquisition Time

Reflecting the similar input circuitry, each standard is concerned with errors due to the input impedance. In addition, they each are concerned about the analog circuit parameters of the input -- called transfer characteristics by the oscilloscope standard and called analog bandwidth and step response parameters in the waveform recorder document -- because these parameters could lead to measurement error. Each document also deals with general instrumentation characteristics such as the susceptibility to electromagnetic interference and the nonlinearity of the instrument's response. In addition to the common parameters between the devices, there are also parameters which are specific to a particular device. The cathode ray tube of the oscilloscope, for example, contains geometric distortions which can affect measurement accuracy.

The introduction of the newer technology, moreover, also introduces newer error sources. One convenient and conventional way to characterize these errors in digital waveform recorders is by determining the parameter called the effective number of bits or simply the effective bits. The motivation for this means of characterization is the realization that an ideal n-bit waveform recorder would have a calculable signal-to-noise ratio, S/N. This ratio is given by the expression [6]:

$$S/N_{ideal}(\text{decibels}) = 6.02n + 1.76 \qquad (1)$$

To determine the number of effective bits of a non-ideal waveform recorder, a high purity sine wave is generated and applied to the input of the recorder. The output data is fitted to a sine wave (using, for example, a least squares fitting algorithm) and the fitted curve is compared to the original data to determine a signal-to-noise ratio. Using this measured signal-to-noise ratio, the number of effective bits n_i is calculated using the relationship:

$$S/N_{measured}(\text{decibels}) = 6.02n_i + 1.76 \qquad (2)$$

One of the error sources which is at least partially accounted for by this test is that due to the acquisition time of the waveform recorder. The recorder requires a nonzero amount of time to acquire a sample. This time could produce a significant error if the rate of change of the input voltage waveform is sufficiently large [7]. Information on the number of effective bits as a function of frequency can be used to bound, if not to correct for, this error.

Effective bit characterization is useful, and is in widespread use, but it must be recognized that it is not sufficient to determine the errors in an impulse measurement. One limitation of the approach is that it is insensitive to any dependence of the gain of the recorder on the frequency of the incoming signal. In addition, due to such factors as thermal effects in the recorder, it is possible that the transient response will differ from the steady-state response [8]. If this is the case, the measurement of a pulse will be subject to additional errors beyond those determined in an equivalent bit test.

The third type of data recording system shown in figure 1 is the newest type [9], so no standardized compilations of error sources are yet under development. The concept of such a system is that the signal to be measured is encoded as the intensity of a light beam as a function of time. This light beam impinges on the face of a swept image-converter tube. At the tube's photocathode, the light beam is converted to an electron beam. A deflection circuit is used to deflect the electron beam which impinges upon a phosphor screen producing a display of intensity vs. position. This display is digitized using a two-dimensional photodiode array and the digital signal is stored. Careful consideration shows that this type of system may have advantages, e.g. higher speed or lower cost per data channel than conventional systems. However, the complexity of the system will probably raise challenges in the identification of the most significant sources of error and in the development of appropriate calibration techniques.

Summary

This brief introduction to present activities in the area of data acquisition is intended to underscore the fact that this field is robust and growing. New technologies are augmenting previous capabilities to produce measurement systems which are better, and better characterized than they were in the past. In addition, improved understanding of their capabilities and shortcomings is leading to a more sophisticated use of existing systems.

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